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NEIDIUM RUDIMENTARUM (BACILLARIOPHYCEAE), A RARE SPECIES WITH NOVEL RUDIMENTARY CANALS AND AREOLAR OPENINGS FROM THE TEMPERATE REGION OF NORTH AMERICA

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ABSTRACT. *Neidium rudimentarum* is a rare species identified from only two localities in the United States. Rudimentary canals on either side of the valve, that extend 10–25 μm from the terminal apices, are unique to this species within the genus. At the internal termination point, the canals open into chambered areolae that form a well-developed matrix of interconnected chambers. In addition to the canals, linear slits are unique for the external opening of the areolae. The type locality Bluehole pool/Inskip River, New Jersey is a cool-water, oligotrophic system with a groundwater source from the Potomac-Raritan-Magothy aquifer. *Neidium hamatum*, from Rio Tapajós, Brazil is the closest known taxon in general morphology, however it has complete longitudinal canals extending from apex to apex. The rudimentary canal of this species is in distinct contrast to the multiple canals of *N. tumescens* and is thus far unique within the genus *Neidium sensu lato*.

Key Words: diatom, North America, rare species, rudimentary canal

In 1959, an interesting *Neidium* species, *Neidium rudimentarum*, was described with longitudinal bands (canals) present only at the apices (Reimer 1959). This incomplete or rudimentary canal formation is unique to this species, especially considering that the primary character for *Neidium* is the presence of longitudinal canals extending along the valve margin. The observed occurrence from two localities in the United States [New Jersey, Winslow, Blue Hole, Inskip River (Boyer Collection, *W-6-23*, ANSP) and New Hampshire, Grafton County, Crane

Pond (*G.C. 53811b*, ANSP)] is also of interest, given the extensive collecting of diatoms across North America from both living and historical sediments. This study examines the morphological structure of *N. rudimentarum* and compares it to related taxa within the genus. Further, the diversity of canal structures is explored with reference to the morphology of the genus *Neidium sensu lato*.

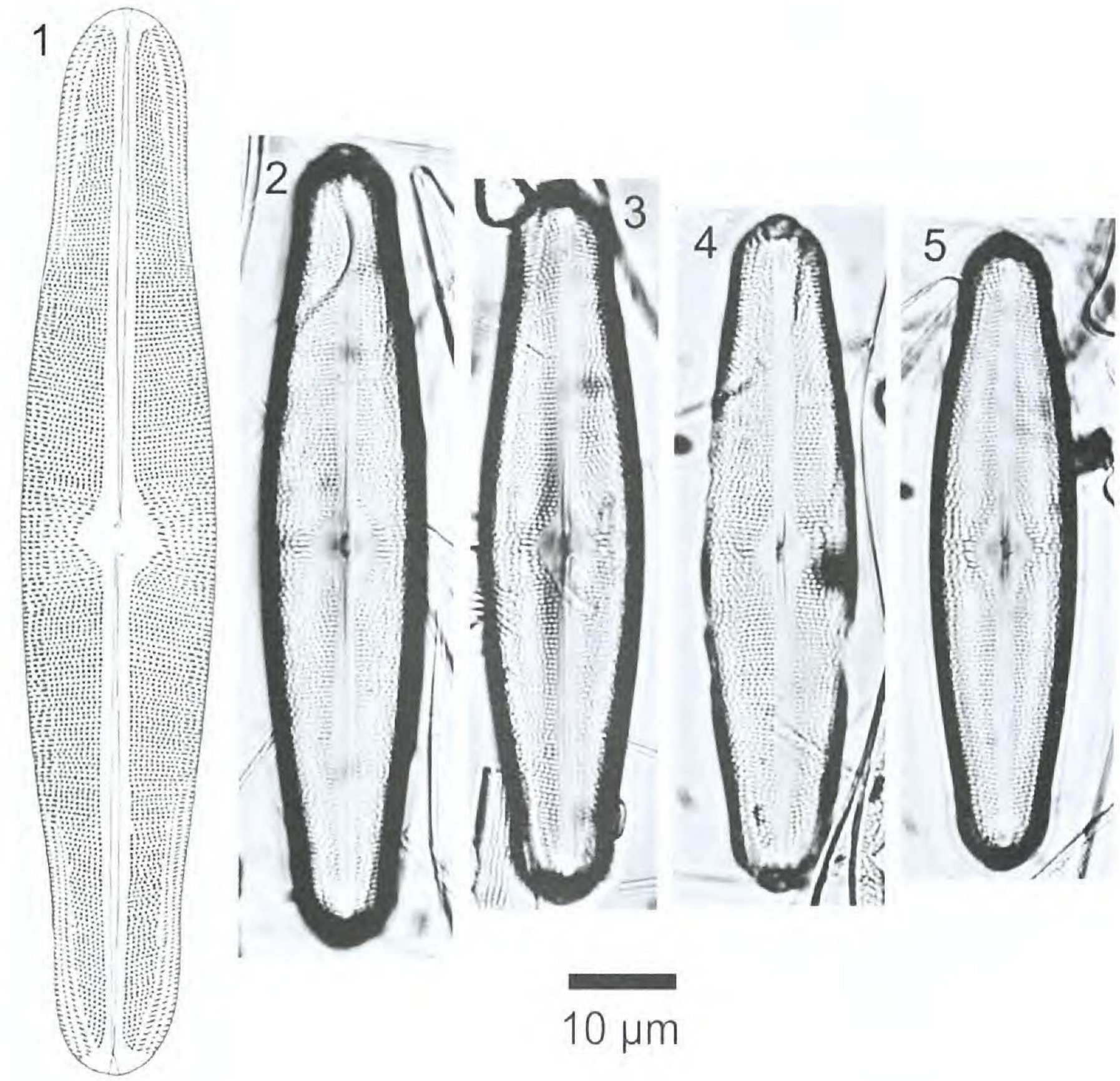
MATERIALS AND METHODS

Specimens of *Neidium rudimentarum* from the holotype slide (*BOYER-W-6-23*, ANSP) were observed and measured using a Wild M20™ microscope equipped with bright field optics. In addition, type material was acquired for examination from the Academy of Natural Sciences (ANSP). The type material was mounted using Hyrax® and deposited at the Canadian Museum of Nature under *68356* (CANA). Morphometric observations were made on the *68356* CANA slide with a Leitz™ Dialux 22 microscope (LM) equipped with bright field and phase contrast optics. Subsamples from the type material were also mounted for scanning electron microscope (SEM) examination following the procedures of Hamilton et al. (1990). An Hitachi S-530 SEM and a FEI XL30 Environmental SEM were used to study detailed morphometric structure using acceleration voltages ranging from 5–15 kV. Diatom terminology follows that of Anonymous (1975), Ross et al. (1979), and von Stosch (1975).

RESULTS

Neidium rudimentarum Reimer, *emend.* Proc. Acad. Nat. Sci. Philadelphia 111: 1–35. 1959. TYPE: U.S.A. New Jersey: Winslow, Blue Hole, Inskip River, 26 May 1923, *T.C. Palmer* (HOLOTYPE: Boyer Collection, *BOYER-W-6-23*, ANSP; subsamples of type material: *68356*, CANA).

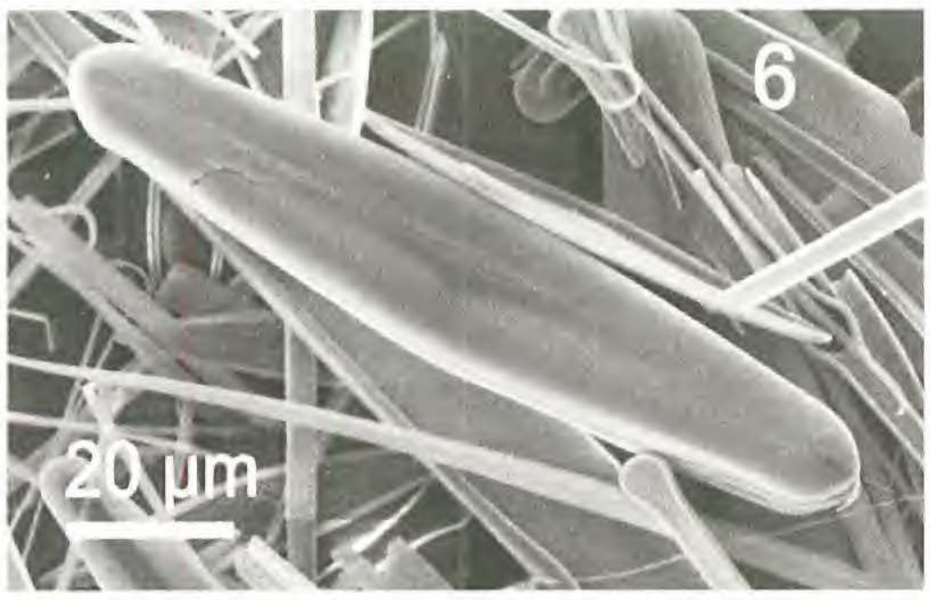
Valves linear to linear-elliptical, 52–110 μm in length, 11–20 μm in width, striae 19–24 in 10 μm with 12–18 areolae in 10 μm (Figures 1–5). Apices are obtusely rounded to subcuneate. The raphe is filiform with deflected central raphe ends that do not terminate in distinct fissures (Figures 1, 3, 5). The terminal raphe fissures are partially covered with an apical flap (lacinia), which appears in LM as a "bifurcation" of the terminal raphe end (Figure 1). The central area is round to slightly elliptical, covering 27–40% of the valve width. Striae around the central area exist as slits that extend towards the valve mantle. The uneven

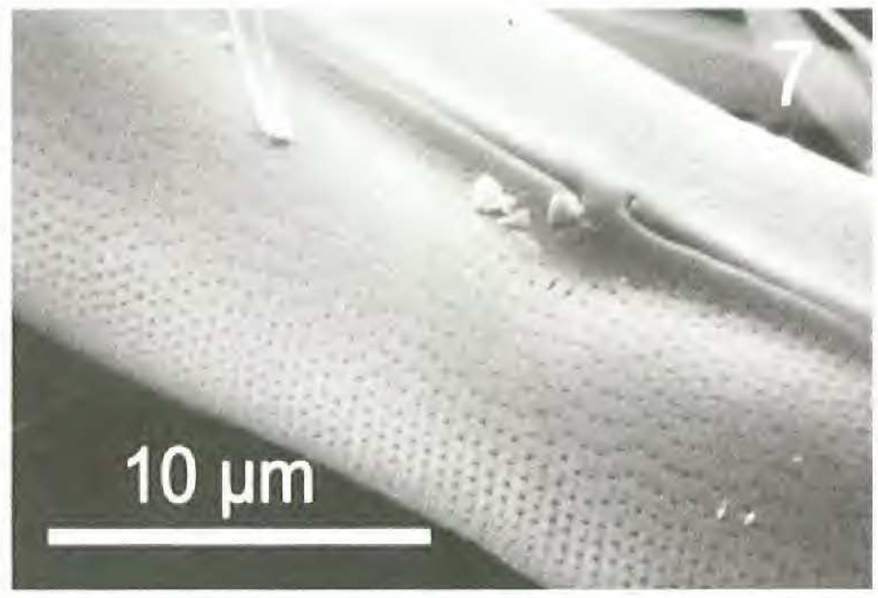


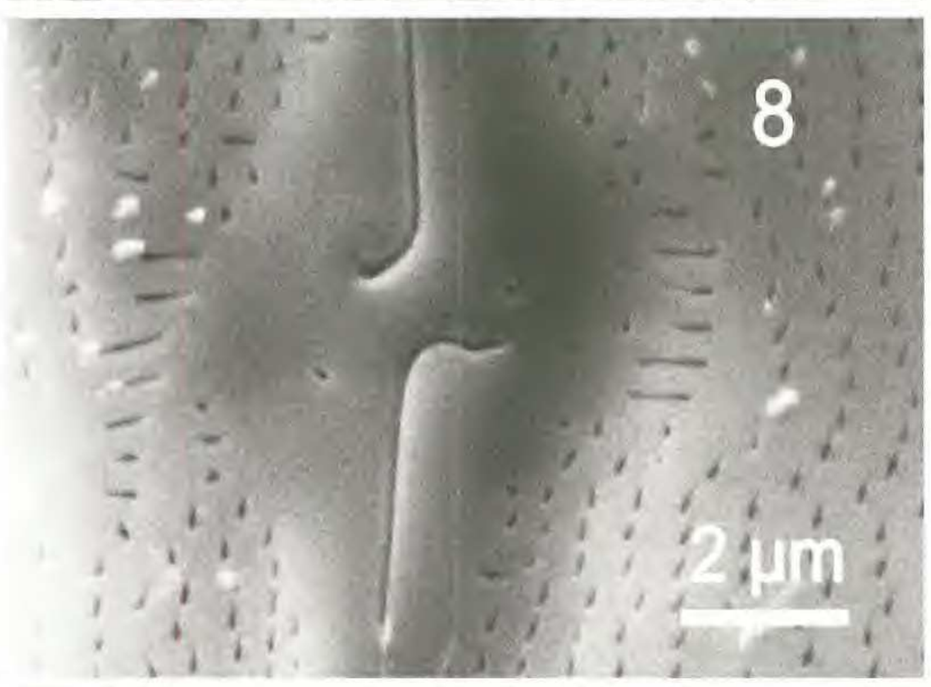
Figures 1–5. Line drawing and LM photomicrographs of *Neidium rudimentarum*. 1. Line drawing of the holotype printed with permission from Reimer in Patrick & Reimer (1966). 2–5. Bright Field light micrographs taken from *68356*, CANA (two slides).

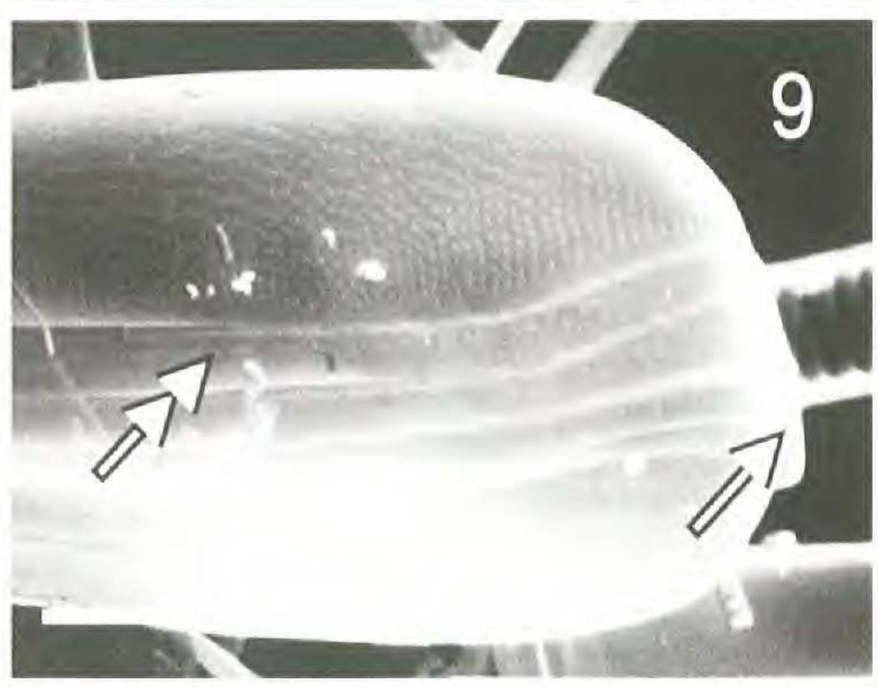
spacing of areolae, especially evident along the valve margin, creates a "wavy" orientation of these pores, especially around the central area (Figures 1–5). Two longitudinal canals originate from the apices and quickly terminate 10–25 µm from the apex (Figures 1–4). Striae are slightly radiate at the center to slightly convergent at the apices. This emended species description differs from the original (Reimer 1959) by expanding the size range, increasing the stria count, introducing an areola count, and clarifying the ultrastructure of the longitudinal canal and areolae.

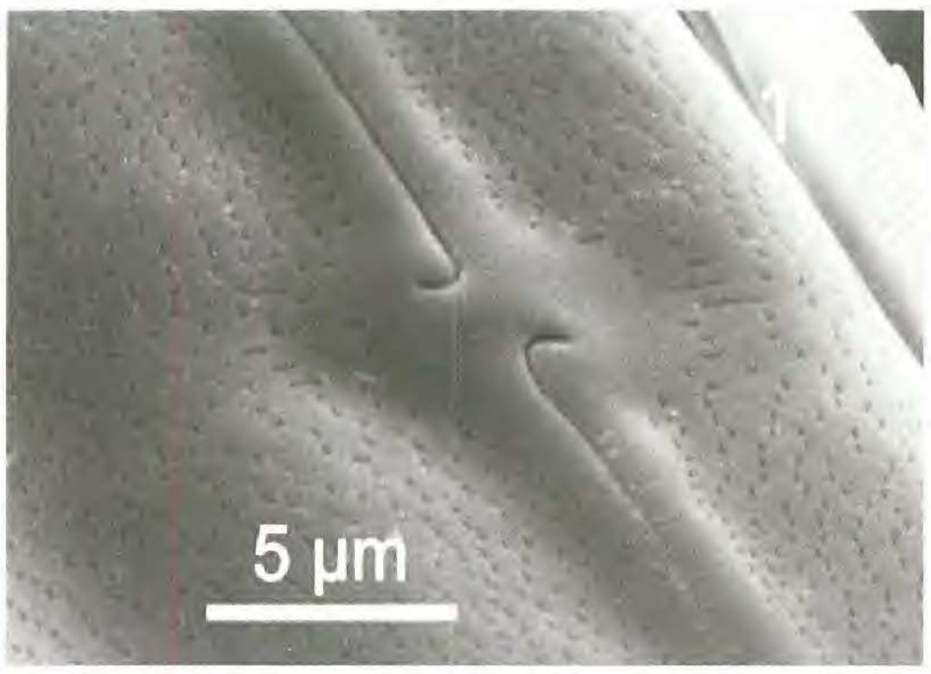
Externally, the valve shows many structural characters that differ from other *Neidium* species (Figures 6–13). The raphe is composed of two straight branches running the length of the valve and sits on a solid

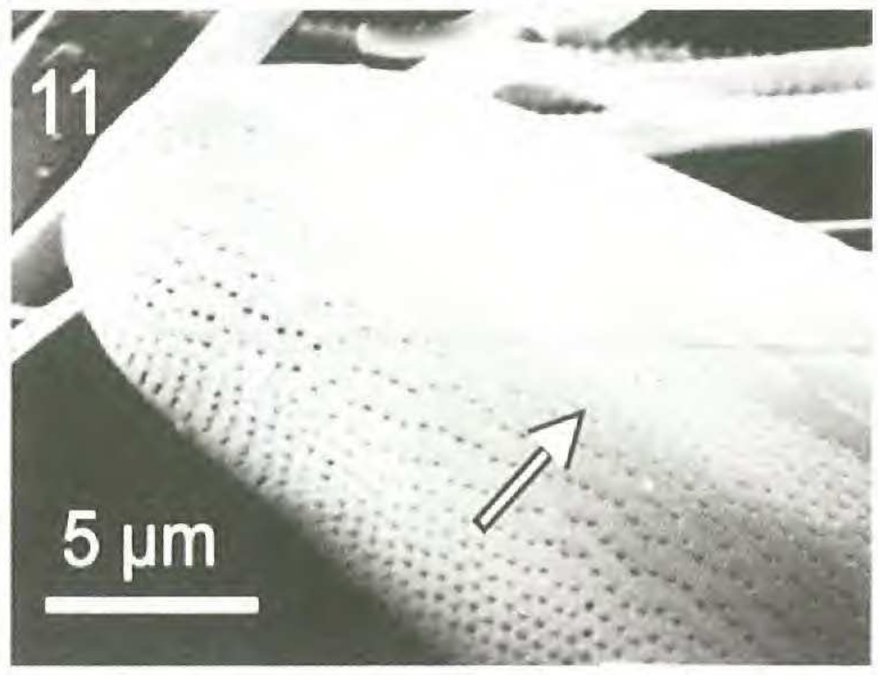


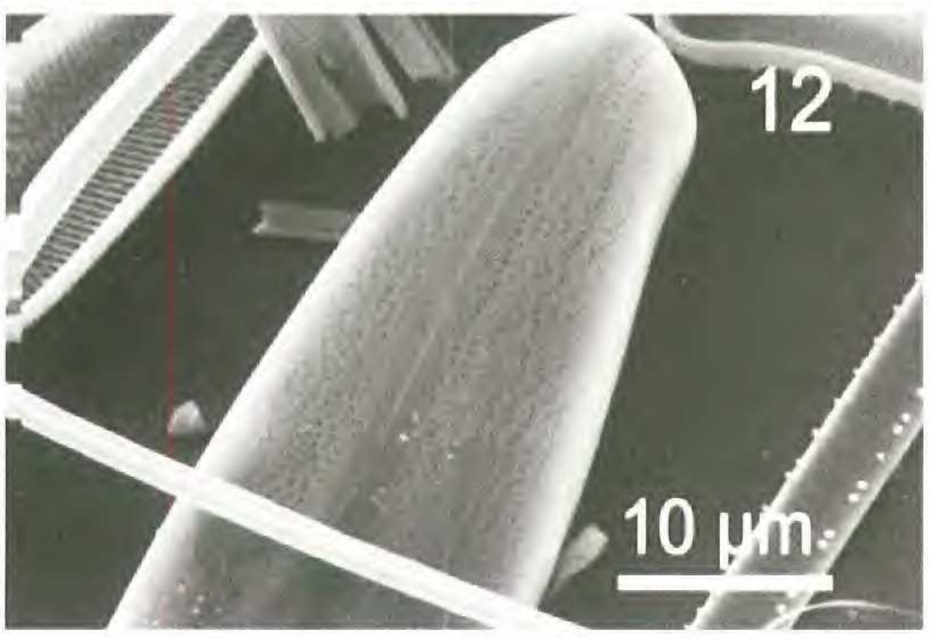


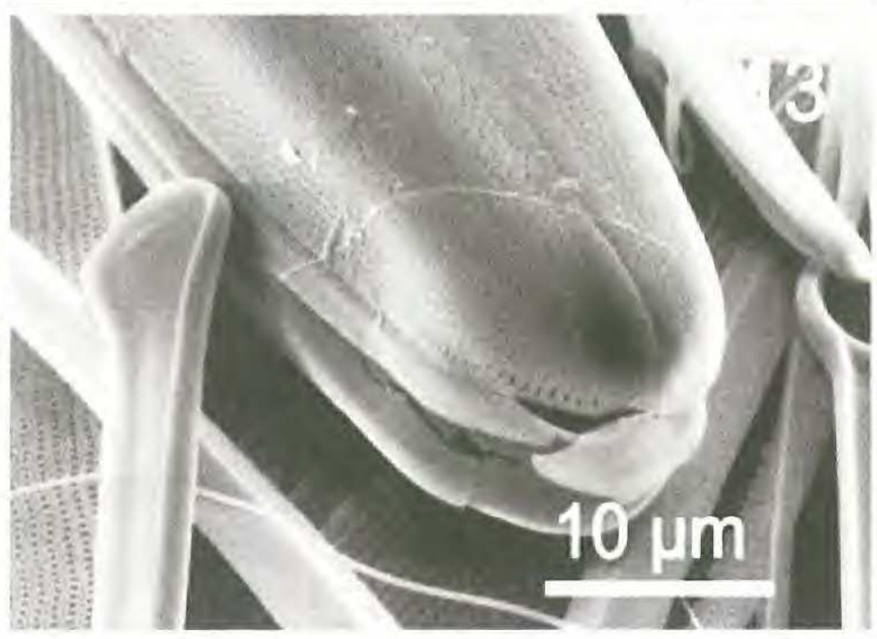












Figures 6–13. *Neidium rudimentarum*, SEM, external surface valve structure. 6. Whole valve. 7. A raised central area with isolated depressions and clearly hooked raphe endings. 8. Central area. 9. Girdle view of frustule apex, single arrow indicates the ligula, double arrow shows the poroid pores on the pars exterior of a pleura. 10. Central area with raised axial area. 11. Apex, mantle projection showing a longitudinal canal starting from apex and ending early along the valve margin, arrow indicates termination point of canal. 12. Apex, valve projection showing the complete longitudinal canal. 13. Apex, terminal projection highlighting the basal

(non-ornamented) axial area, which is elevated at the terminal apices (Figures 6, 9, 11, 12). The axial area at the center of the valve is also elevated and surrounded by a depressed central area (Figures 7, 8, 10). The raphe terminates at the mantle under a small but distinct lacinia that extends to the mantle base (Figures 9, 13). Striae are composed of linear slit-like areolae, which become slightly rounded to elliptical along the mantle face (Figures 7, 8, 10, 11). Long elliptical areolae also exist along the base of the mantle at the apices (Figure 13). Around the central area, the first set of areolae are lineolate and oriented perpendicular to other areolae creating the slits observed in LM (Figures 8, 10). The central area is clearly elevated and may sometimes have depressions, which are not areolae (Figure 8). When the valve deteriorates, the areolae may become round in appearance (Figure 11). The longitudinal canal does not extend far from the apices and terminates into two or more areolae (Figures 6, 11, 12). Three to four pleurae are typically present with a complete frustule. The pleurae are incomplete ligulate bands opening alternately at the apices (Figures 9, 13). Each pleura has one row of pores along the upper pars exterior edge.

Internally, the raphe is elevated on the sternum, ending terminally in helictoglossae and centrally with a bimodal central nodule (Figures 14, 15, 16). The raphe is a key and slot formation. The small longitudinal canals at the apices open internally through enlarged elliptical slits that are especially evident at the apex (Figures 15, 17). The equally spaced areolae are round to elliptical with beveled edges, creating a poroid internal surface. The areolae are composed of small internal chambers within the siliceous valve structure and connect to other adjacent areolae and the longitudinal canal (Figures 14, 16, 18, 19). Other taxa with this type of open-chambered or interconnected areolae include *Neidium amphigomphus* (Ehrenb.) Pfitzer., *N. ampliatum* (Ehrenb.) Krammer, *N. gracile* Hust., *N. hitchcockii* (Ehrenb.) Cleve, and *N. tumescens* (Grunow) Cleve (Hamilton et al. 1995; Reichardt 1995; Siver et al. 2003; unpubl. images). No hymen structures were found on the few specimens observed, however it is presumed that hymens would be present and cover the internal openings of the areolae. This assumption is based on the consistent presence of hymens in other *Neidium* taxa with a similar areolate structure.

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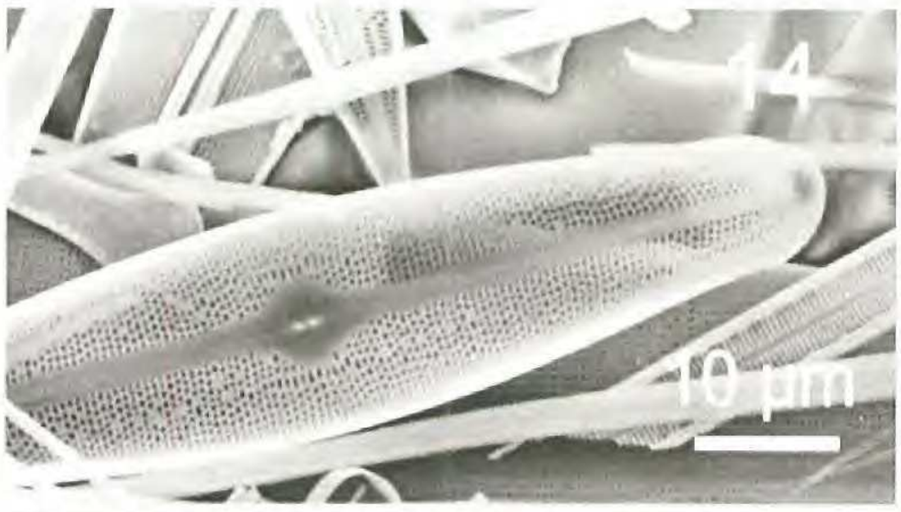
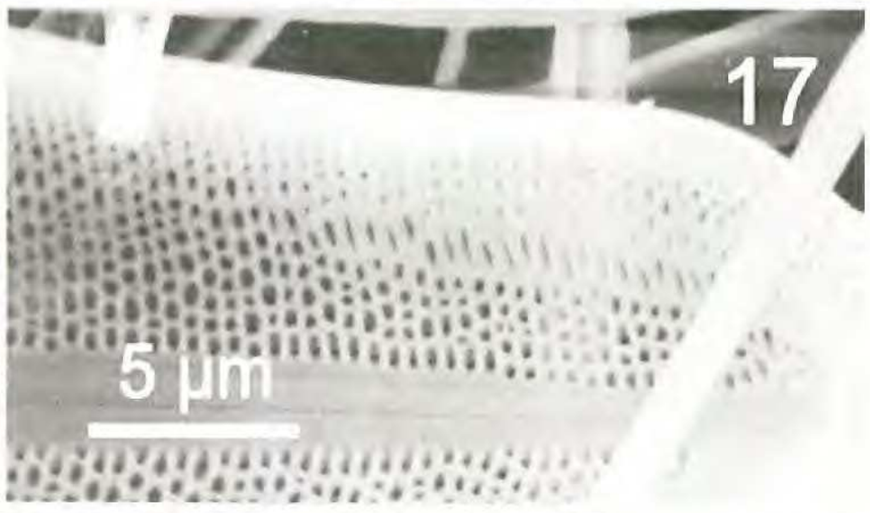
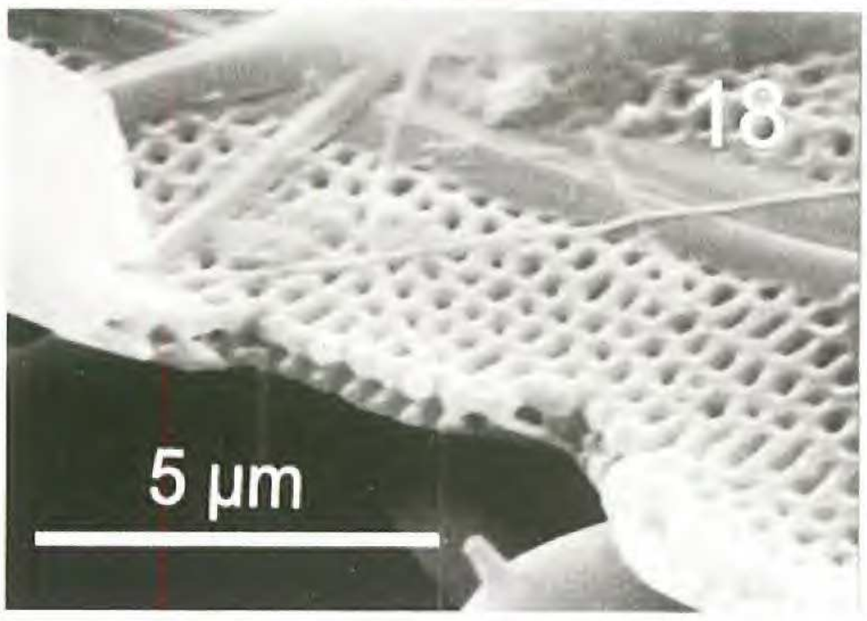
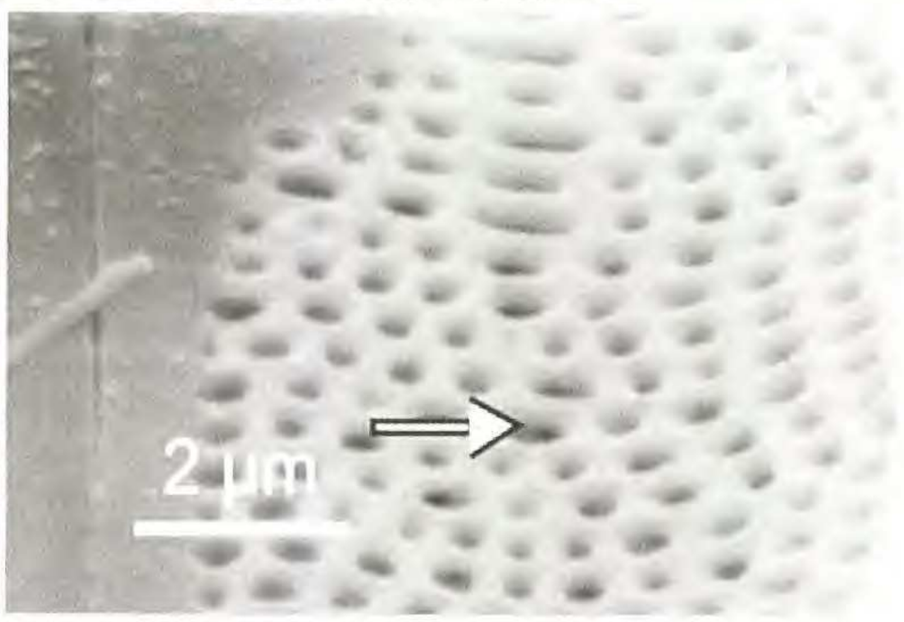
areolae along the mantle, the lacinia partially covers the terminal raphe ending. Note: on tilted specimens scale measures are subject to tilt error.









Figures 14–19. *Neidium rudimentarum*, SEM, internal surface valve structure. 14. Major proportion of valve, with large round areolae. 15. Apex showing the rudimentary canal and large elliptical openings; insert highlights the helictoglossa. 16. Central nodule, areolae slit-like around the central area with bimodal formation created by two adjacent helictoglossae. 17. Apex, internal valve projection, termination of the longitudinal canal is clearly visible. 18. Broken valve illustrating the chambered nature of the areolae. 19. A depressed region around each areola (arrow). Note: on tilted specimens scale measures are subject to tilt error.

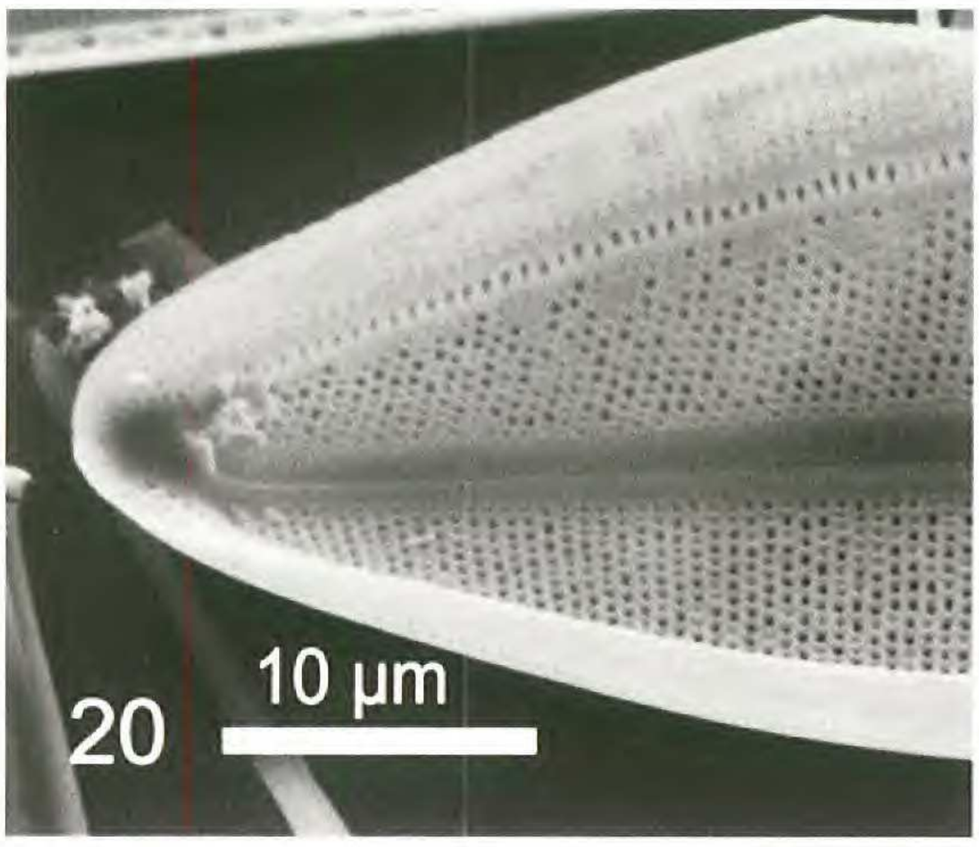
GEOLOGY AND ECOLOGY. The geology of the New Jersey Coastal Plain along the Great Egg Harbor River is Quaternary at the coastal outflow in Atlantic County to Upper Tertiary in the headwaters. The surficial sediments are generally sand and gravel deposits at Great Egg Harbor outflow to sand and green sands in the southern Gloucester County region. The local hydrogeology is a unique part of the Potomac-Raritan-Magothy Aquifer system (Gill and Farlekas 1976). The aquifer is productive in Gloucester and Camden Counties (ca. 50 billion litres of available water measured during 1967) and can be classified as a leaky artesian aquifer (Gill and Farlekas 1976).

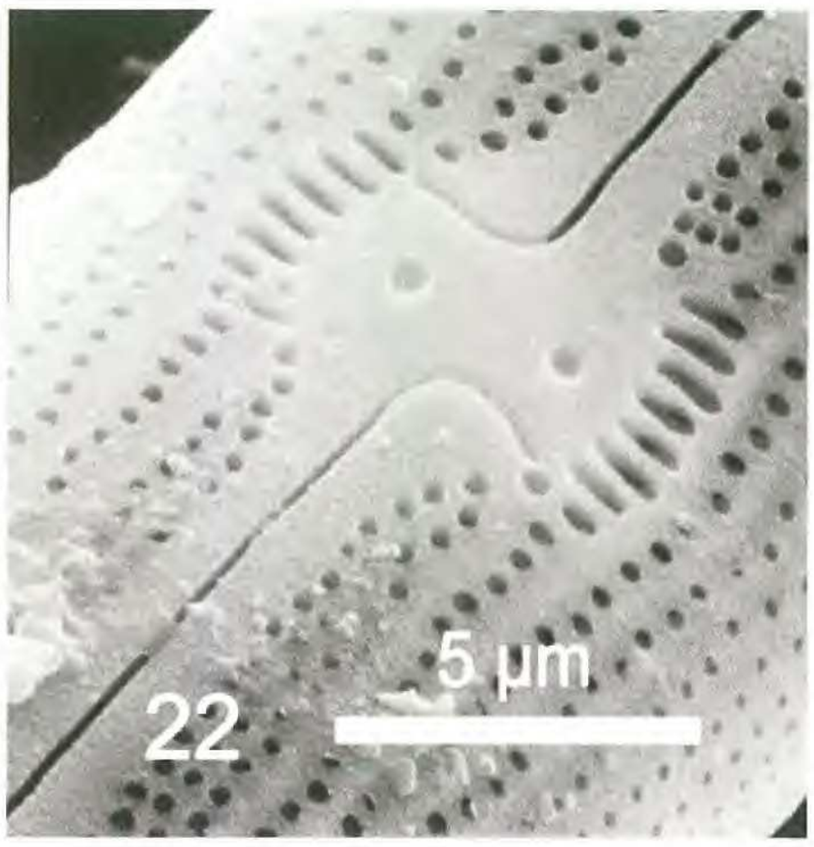
The Great Egg Harbor River flows from the headwaters within the Potomac-Raritan-Magothy aquifer system of the Winslow Wildlife Management Area (Gloucester County) to Great Egg Harbor Bay at Corbin City (Atlantic County), New Jersey. The river, west of Hanington and south of Berlin at Blue Hole pool is 15–25 m wide, and 1–2 m deep, with a predominantly sand cobble bottom. The original sample collected by T. C. Palmer lists the collection site as New Jersey, Winslow, Blue Hole, Inskip River. Although the site description is incomplete, the type locality is clearly Blue Hole (39°37.584′N, 74°53.279′W), located on the west side of Great Egg Harbor River within the Winslow Wildlife Management Area, immediately adjacent to Cecil Inskip Road.

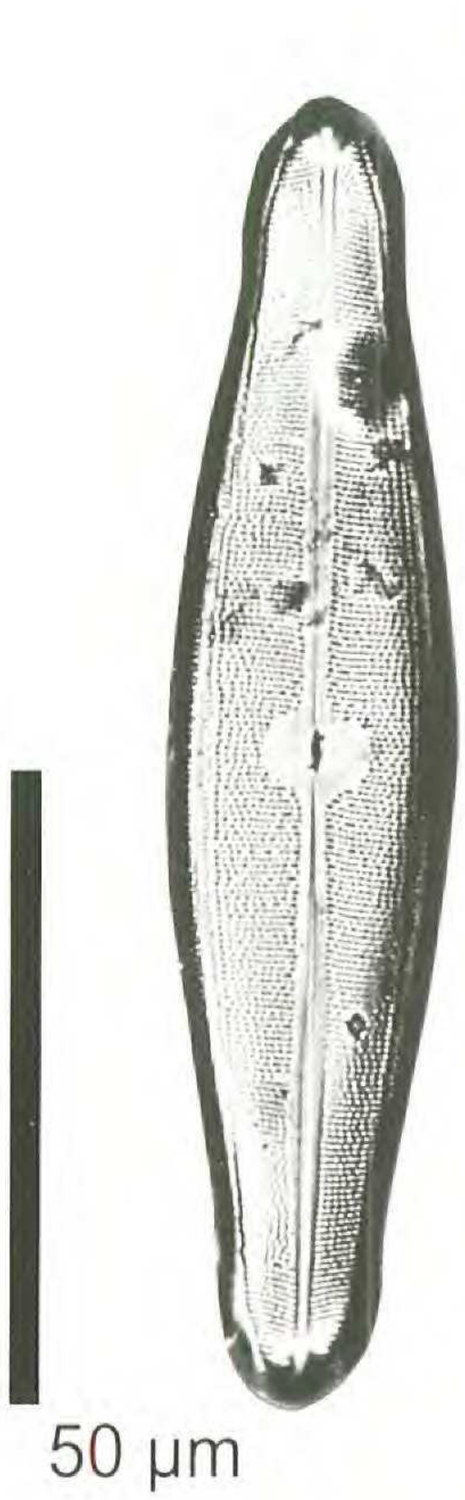
A small article written in a local newspaper (author unknown) suggests that Blue Hole pool is an "ice" cold water pool, separated from the river by a 15 m bank, with the possibility of occasional spring flooding. Blue Hole pool is approximately 40–50 m long, 25 m wide and up to 3 m deep. The water is clear, with light easily penetrating to the bottom. The blue appearance of the water is enhanced by the reflection of light from the white diatomaceous earth and siliceous sediment at the bottom in the pool. The water analysed on October 27, 2003 was acidic (pH 4.3), with a low conductance (44 µS/cm). Allochthonous organic input to the pools (significant leaf accumulation within the near-shore zone) was clearly evident. Other taxa observed at this site of potentially poorly buffered oligotrophic water include *Asterionella* cf. *ralfsii* var. *americana* Körner, *Aulacoseira canadensis* (Hust.) Simonsen, *Brachysira neoacuta* Lange-Bert., *Eunotia zygodon* Ehrenb., *Frustulia rhomboides* (Ehrenb.) De Toni, *Neidium affine* (Ehrenb.) Pfitzer, *N. tumescens*, and *N. ampliatum*.

DISCUSSION

Longitudinal canals along the valve margin are the defining morphological structures for the genus *Neidium*. These canals can vary from one to >10 parallel chambers running along each margin (Figures 21, 22, 23). Single canals can be large and elevated like a keel (e.g., *N. hitchcockii*, *N. gracile*) or small within the valve silica matrix and hard to distinguish from adjacent areolae [e.g., *N. coralieae* Metzeltin & Krammer, *N. catariense* (Krasske) Lange-Bert.]. *Neidium rudimentarum* uniquely lacks a single complete longitudinal canal. Although not complete, this rudimentary canal is easily visible with a morphological structure similar to *N. ampliatum* and *N. hamatum* Metzeltin & Krammer







Figures 20–23. Some *Neidium* species highlighting differences among the taxa. 20. *Neidium ampliatum*. 21. *Neidium hamatum*, similar in morphology with a complete longitudinal canal from apex to apex. 22. *Neidium bergii* with lineate areolae around the central area. 23. *Neidium tumescens*, illustrating the presence of multiple canals adjacent to each other along the margin.

(Figures 20, 21). The areolae are also distinct slits on the external valve face whereas all other known species identified by SEM exhibit simple poroid to elaborate volae-covered areolae (Hamilton et al. 1995, 1996; Metzeltin and Lange-Bertalot 1998; Siver et al. 2003). Even though it lacks a complete canal and rounded externally opening areolae, this taxon clearly belongs within the genus because it contains other typical characters including the presence of deflected proximal raphe endings and laciniae at the apices. In general outline, two taxa are similar to *N. rudimentarum*: *N. hamatum* and *N. ampliatum sensu lato*. However these both have a well-developed complete longitudinal canal along each margin. The almost identical morphology of *N. hamatum* is especially interesting because this taxon is reported as a fossil in the Amazon, Brazil, and it may have some association with *N. rudimentarum*, which is an isolated endemic species less than 4,000 km to the north (Figure 21). The slit-like areolae around the central area and the undulating appearance of the areolae from apex to apex are also similar to structures observed in *N. bergii* (A. Cleve) Krammer (Figure 22). The significance of this similarity is not clear. Ecologically, *N. rudimentarum* is similar to most *Neidium* species preferring low pH, low conductance, and an organically rich benthic habitat.

The genus *Neidium* covers a large morphological range of canal types from one rudimentary canal (*N. rudimentarum*) to >10 well-developed canals (*N. tumescens*, Figure 23). The diversity of forms within the genus and the morphological variability of the species may have some implications in understanding the significance of longitudinal canals and keels which are observed in many genera within the Bacillariophyceae, both marine and freshwater.

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